Fermi National Accelerator Laboratory
P.O. Box 500 Batavia, Illinois, 60510

FERMILAB 83/29
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UC-41

Environmental Monitoring Report

for Calendar Year 1982

May 1, 1983

Samuel I. Baker

Operated by Universities Research Association Inc.
Under Contract with the United States Department of Energy

Fermi National Accelerator Laboratory
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ENVIRONMENTAL MONITORING REPORT
For Calendar Year 1982

by
Samuel I. Baker
May 1, 1983

Laboratory Work
by
R. L. Allen, S. I. Baker, J. H. Baldwin
P. J. Linden and J. R. Phillips

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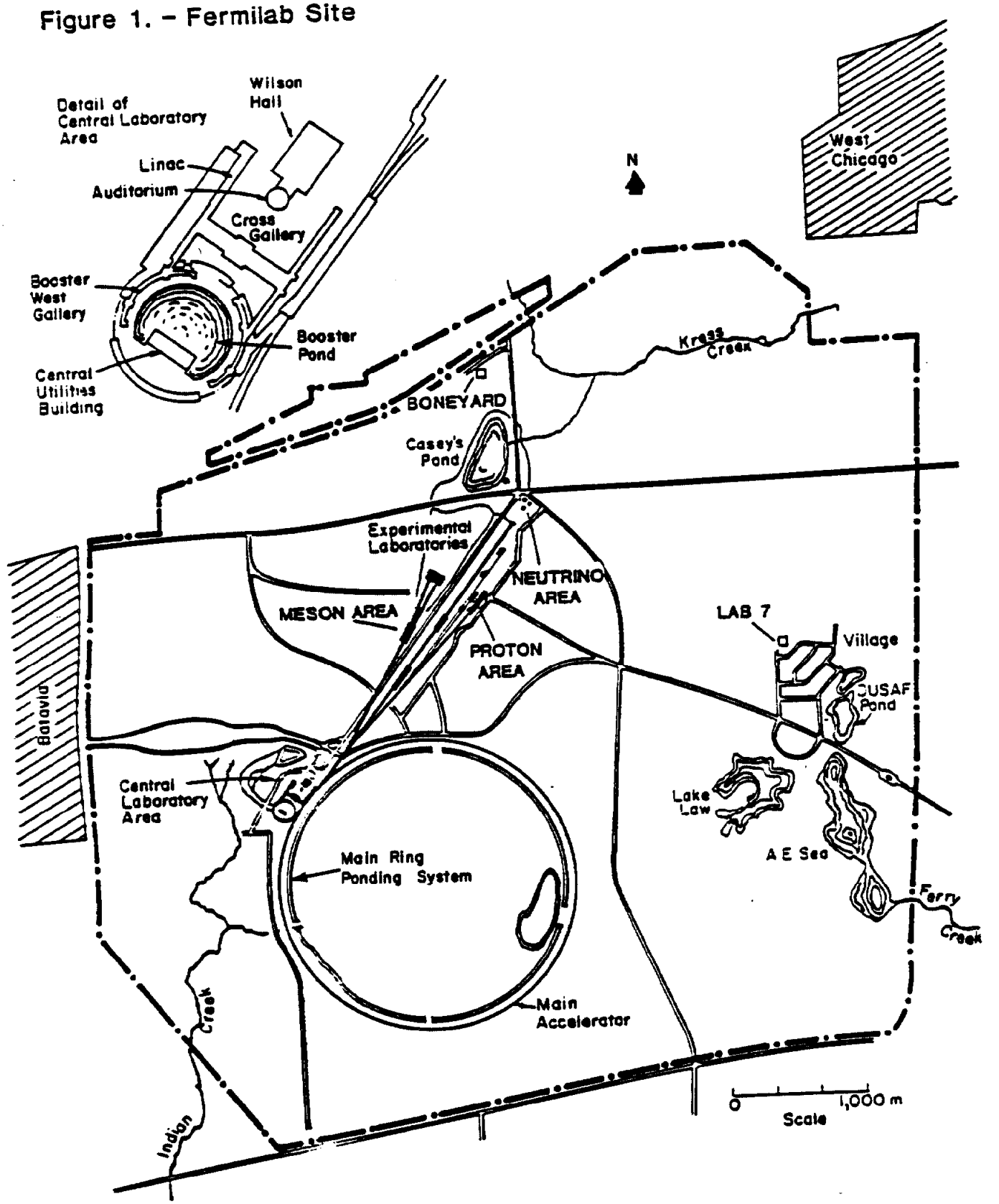
1. Introduction

This report gives the results of the environmental monitoring program at Fermi National Accelerator Laboratory (Fermilab) for Calendar Year (CY-) 1982. The Fermilab Facility is a proton synchrotron with an original design energy of 200 GeV (billion electron volts). As a result of accelerator improvements, protons were accelerated to an energy of 500 GeV in 1976 and operation at 400 GeV is now routine. The primary purpose of the installation is fundamental research in high energy physics. In addition, cancer patients are being treated using neutrons released by the interaction of 66 MeV protons from the second stage of the accelerator. A major program is in progress to construct, install, and operate a ring of superconducting magnets. The goal is to produce higher energy protons using less electrical power.

The proton beam extracted for high energy physics from the 2 km (1.2 mi) diameter main accelerator is taken to three different experimental areas on site (Meson, Neutrino and Proton Areas in Fig. 1). All three of these areas received proton beams for the first time in 1972. Radioactivity is produced as a result of the interaction of the accelerated protons with matter. Operation of the accelerator produces some radiation which penetrates

Figure 1. – Fermilab Site



1982

the shielding material as well as some airborne radioactivity. Also, some radioactivation occurs in the soil and in the water used to cool radioactive components. Since the Fermilab site is open to the public, this free access necessitates a thorough evaluation of the on-site discharges as well as the potential for off-site releases of radioactive effluents. Thus, an extensive monitoring program tailored to these needs is being carried out.

The Fermilab environmental radiological monitoring program follows, in general, the guidance given in the Department of Energy (DOE) report A Guide for Environmental Radiological Surveillance at DOE Installations.[1] This includes adherence to the standards given in DOE orders, in particular, DOE Order 5480.1A, Chapter XI, which pertains to permissible doses and concentration guides, and gives guidance on maintaining exposures to as low as reasonably achievable (ALARA).[2]

The emphasis has been placed on exposure pathways appropriate to high energy physics laboratories. These pathways include external exposure from direct penetrating radiation and airborne short-lived ^{11}C, and internal exposure from ^{3}H and ^{22}Na in water, primarily drinking water. There is one unique characteristic at Fermilab which requires consideration and that is the use of large volumes

of sand and gravel in two locations to assist in stopping the high energy protons and secondary particles. Although the ground water beneath these two areas is protected by membranes impervious to water and by underdrain systems to collect the water, monitoring is necessary.

Monitoring results are also reported for nonradioactive pollutants. Included as pollutants are pesticides used in weed, insect, rodent, and algae control. Also, another pollutant, a corrosion inhibitor containing zinc and chromium (as chromate), was formerly used in one of the water systems. Discharge underground and subsequent surfacing required monitoring. Although the use of chromate has been discontinued, monitoring for chromate has continued in CY-1982. The CY-1982 result is reported as well as those from monitoring the performance of the sewage treatment plant on site. Discharges of suspended solids from this plant have sometimes exceeded permit limits.

Fermilab is located in the greater Chicago area (Fig. 2) on a 27.5 km^2 (10.6 mi^2) tract of land in an area which is rapidly changing from farming to residential use. There are many municipalities in the vicinity, resulting in a distinct pattern of high population concentration.

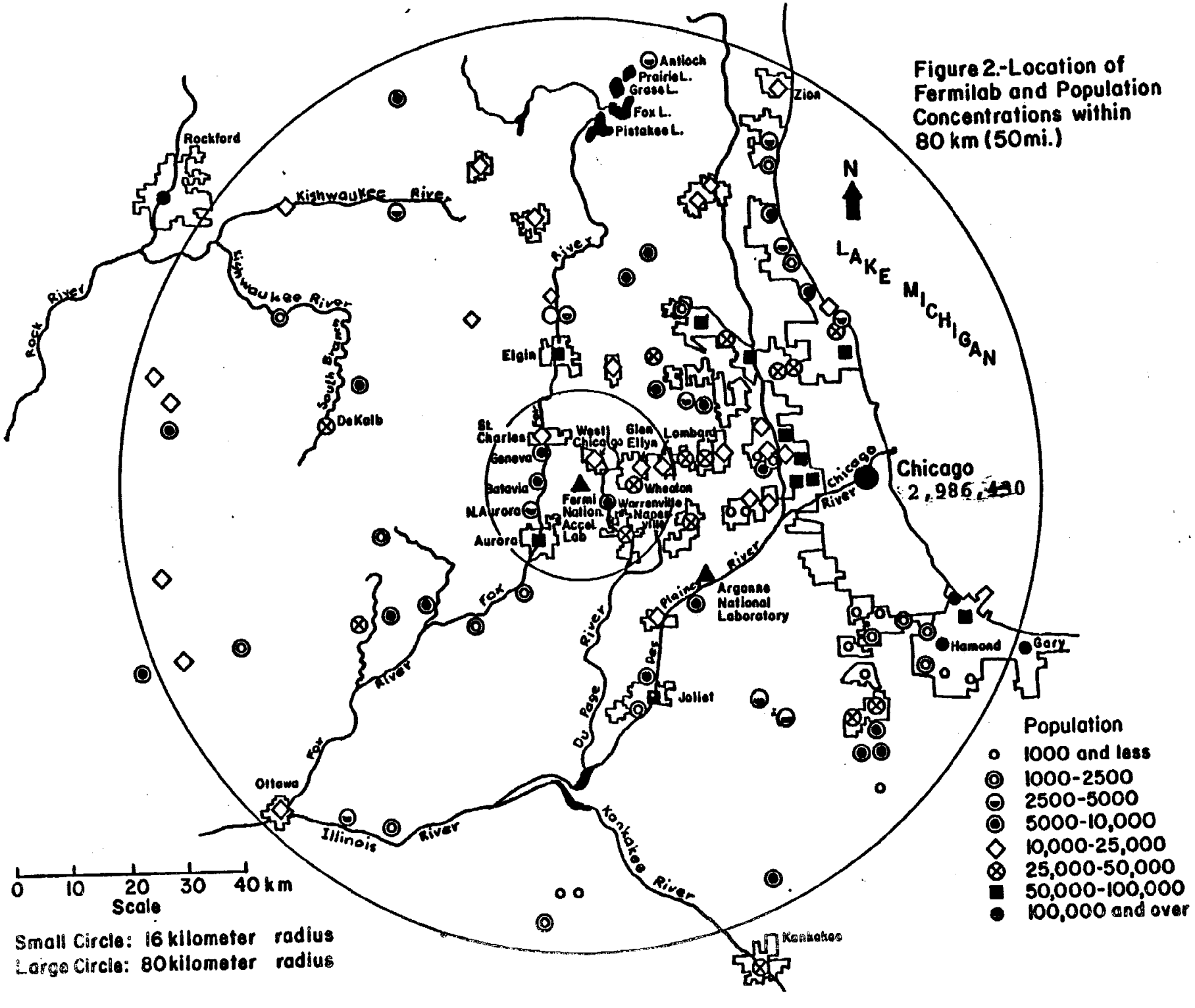


Figure 2.-Location of Fermilab and Population Concentrations within 80 km (50mi.)
N
LAKE MICHIGAN
Antioch
Prairie L.
Grass L.
Fox L.
Pistakee L.
Zion
Rockford
Kishwaukee River
Rock River
Kishwaukee River
South Branch
DeKalb
Elgin
St Charles
West Chicago
Glen Ellyn
Lombard
Geneva
Batavia
Wheaton
Fermi National Accel Lab
N.Aurora
Warrenville
Naperville
Aurora
Chicago
2,986,430
Chicago River
Plainfield
Argonne National Laboratory
Fox River
Du Page River
Joliet
Hamond
Gary
Ottawa
Illinois River
Kankakee River
Kankakee
0 10 20 30 40 km
Scale
Small Circle: 16 kilometer radius
Large Circle: 80kilometer radius
Population
1000 and less
1000-2500
2500-5000
5000-10,000
10,000-25,000
25,000-50,000
50,000-100,000
100,000 and over

1974

Within a 3 km (2 mi) distance from the Laboratory boundaries, Batavia (pop. 12,574), Warrenville (pop. 7,519), and West Chicago (pop. 12,550) can be found.[3]

The two major environmental features near the Laboratory are the Fox River to the west, which flows south through Batavia with an average of 1900 million liters (500 million gallons) per day, and the west branch of the DuPage River which passes east of the site flowing south with an average of 265 million liters (70 million gallons) per day through Warrenville. The rainfall on site during 1982 was 99 cm (39 in).[4] The land on the site is relatively flat with a high area, elevation 244 m (800 ft) above mean sea level (MSL), near the western boundary and low point, elevation 218 m (715 ft), above MSL, toward the southeast. The drainage of the ground water and most of the surface water is toward the southeastern corner of the Laboratory, toward the DuPage River. A somewhat smaller amount drains to the southwest, toward the Fox River. The drinking water in many of the surrounding communities comes from deep wells usually drilled 360 m (1200 ft) deep into the Cambrian/Ordovician aquifer system.[5]

In CY-1982 the meteorological data was obtained from the National Weather Service Office at O'Hare International Airport, Chicago, Illinois. O'Hare Airport is not

significantly farther away than Argonne National Laboratory where data was previously obtained. In CY-1982 the average wind speed at O'Hare Airport was 4.5 m/sec (10.1 mi/hr). Fermilab is about 43 km (27 mi) from the airport and the terrain between them is relatively flat.

Although the Laboratory is open to the public, no hunting is permitted on the site. Fishing is permitted in all lakes and ponds except the Booster Pond and Main Ring ponding system (Fig. 1) where access is restricted because of electrical and mechanical safety considerations. A large number of other recreational activities, such as hiking, baseball, and other sports, is permitted.

Earth shielding has been used to eliminate the radiation hazards in most places. Fences and interlocked enclosures are in place where access still needs to be controlled.

2. Summary

The accelerator operated routinely at 400 GeV during CY-1982 with about the same number of protons accelerated during CY-1982 as in CY-1981.[7] The total number of protons accelerated in 1982 was 1.6×10^{19}. This total is lower than the average of 2.0×10^{19} for the preceding five years. The lower total was the result of an extended shutdown from June 14 until the end of the year for construction and because of a shortage of operating funds. Typical operation was at about 50 percent of the design intensity of 5×10^{13} protons per acceleration cycle. Thus, environmental monitoring in CY-1982 was done under operation conditions not grossly different from those in the past and those expected in the future.

During CY-1982 there were no abnormal occurrences which had an impact on the facility and its operation. Chromate corrosion inhibitors, which were used in the past in water treatment systems and have a potential for environmental pollution, were not used this year. No copper sulfate was used this year to control algae and weed growth in ditches. This year 0.18 km^2 (45 acres) was sprayed with 2,4D for controlling noxious weeds. In the past as much as 10 km^2 (2500 acres) was sprayed with 2,4D.

The maximum potential radiation exposure at the site boundary during CY-1982 (fence line assuming 24 hr/day occupancy) was 0.5 mrem compared to 1.8 mrem last year. This dose would correspond to 0.1 percent of the standard of 500 mrem for an individual who is not a radiation worker (Section 5).

The total potential radiation exposure to the general off-site population from Fermilab operations during CY-1982 was 3 person-rem compared to 11 person-rem last year. The primary sources of potential exposure were penetrating radiation from neutrons and airborne radioactivity this year. All exposure was from external radiation, as was the case in the past. Thus, the 50 year dose commitment from operations in 1982 is expected to be the same as the exposure received in 1982.

Airborne radioactivity was released across the site boundary in small amounts during the first half of the year from the stack ventilating a Neutrino Area enclosure where the proton beam strikes a target. The radioactive gas was primarily ^{11}C, total quantity released was 1.05 kCi, and the maximum dose at the site boundary was 0.2 mrem for 1982. The average concentration at site boundary based on measurements at the stack was 0.04 percent of the Concentration Guide (Sections 3.2 and 5). There was also a

controlled release of tritium in tritiated water evaporated as a means of disposal. The total quantity released to the atmosphere in CY-1982 was 58 mCi, about 14% of last year's release. The concentration at the site boundary was less than 0.01 percent of the Concentration Guide (Sections 3.2 and 5), resulting in a negligible off-site exposure. The off-site release of tritium in surface water totaled approximately 530 mCi, about 80% of last year's release. The primary source of tritium is one sump discharging in the Neutrino Area from an underdrain system beneath the target which receives most of the protons.

3. Monitoring, Data Collection, Analyses, and Evaluation

The three types of accelerator-produced radiation requiring environmental monitoring are discussed below. These radiations have direct pathways to the off-site population. Other more indirect pathways, such as through the food chain, have received much less attention to date. The decision on what to monitor is based on the type of operation, radionuclides released, potential hazard, and monitoring results from this and other high energy physics laboratories.

3.1 Penetrating Radiation

Operation of the accelerator at current energies and intensities results in production of some penetrating radiation (primarily muons and neutrons) outside the shielding. Although the shielding has been designed to be adequate for this operation, monitoring for purposes of determining actual radiation levels both on and off the site is necessary.

A large network of detectors was used to monitor penetrating radiation. At the end of CY-1982 there were approximately 120 detectors deployed around the site for the

main purpose of protecting on-site personnel. The majority of these detectors were connected to a data logger which automatically recorded the radiation levels for subsequent examination.[8] Seven detectors were used primarily for environmental radiation monitoring. Five were large volume, 110 liter, ionization chambers (called Hippos) for gamma-ray and charged particle detection. Three of the five were located in the Neutrino Area (Fig. 3), one was at the Boneyard (Fig. 1), and one was at Lab 7 (Fig. 1). The remaining two detectors were large scintillation counters. One of these is located near the site boundary (Environmental Monitoring Station in Fig. 4). The other is used near the experimental areas (W43 in Fig. 4) to detect ^{11}C in the Neutrino Area radioactive gas releases.

The Mobile Environmental Radiation Laboratory (MERL) was used for determining the exposure levels at the site boundary and for locating the sources of penetrating radiation such as muons and neutrons.[7,9,10,11] The MERL is a four-wheel-drive vehicle equipped with two 20 cm x 20 cm (8 in x 8 in) scintillation counters, one approximately 15 cm (6 in) behind the other, for muon detection. It also has a dePangher "long counter" for neutron detection.[7]

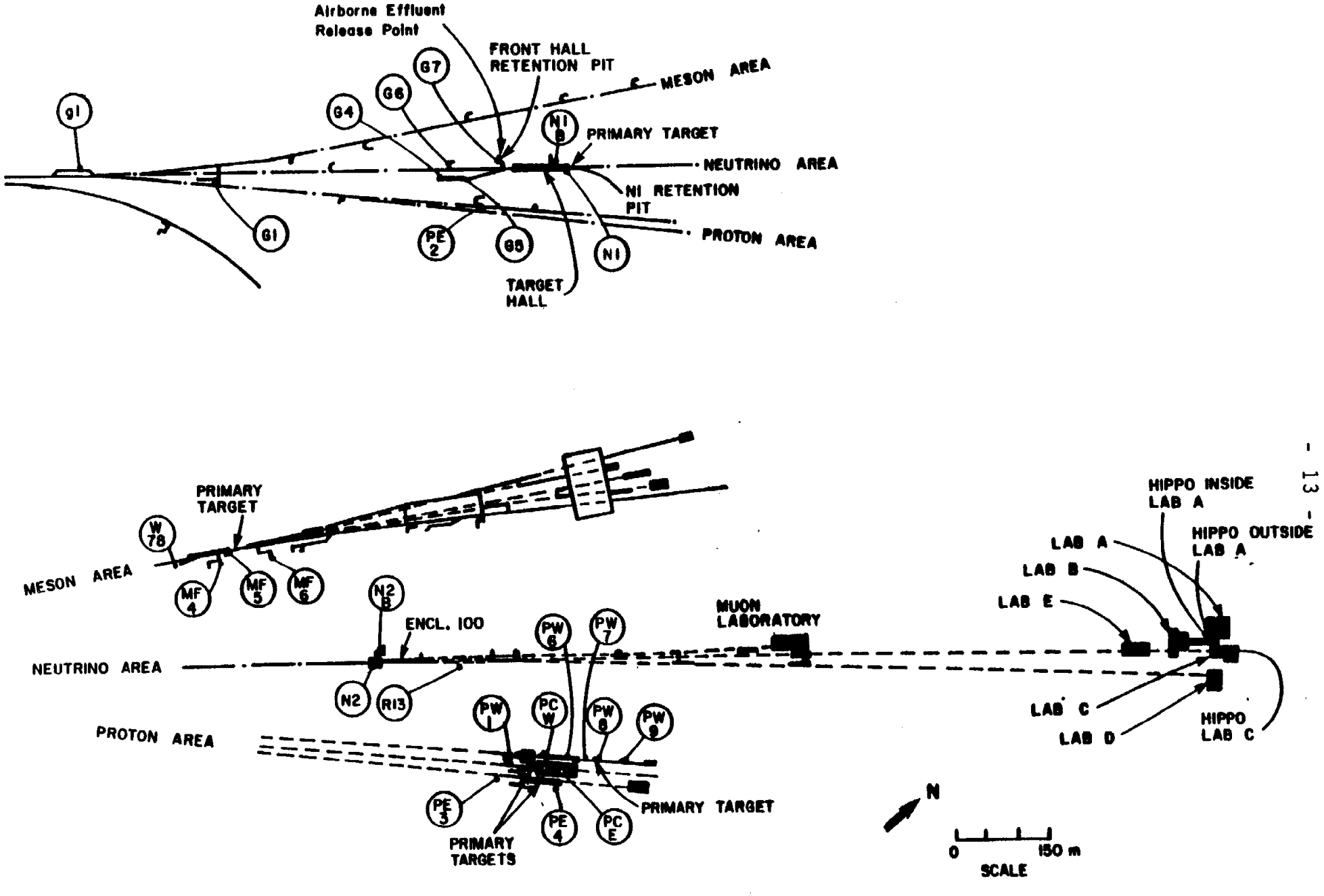
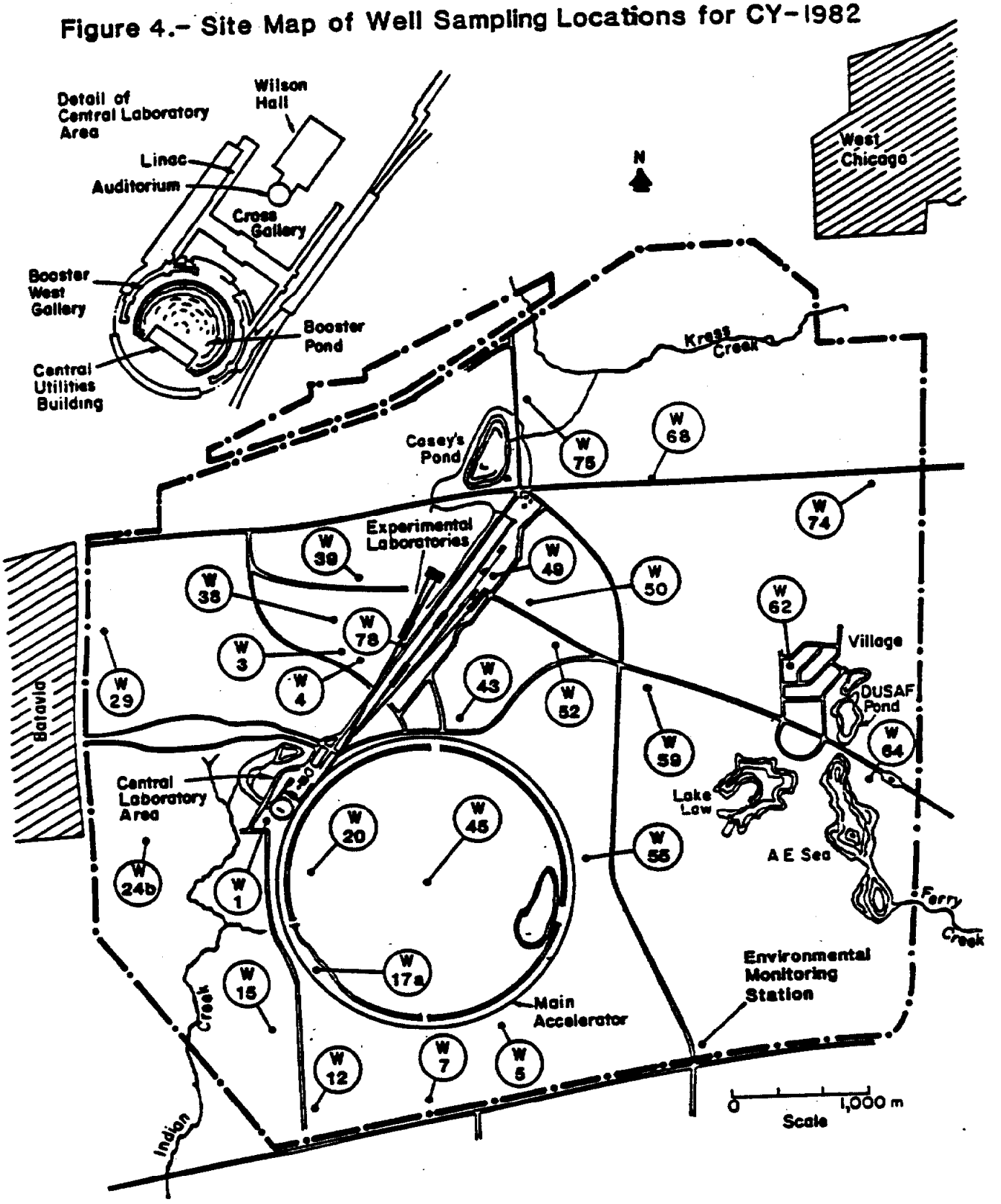


Figure 3. Sampling Locations in External Experimental Areas

Figure 4.- Site Map of Well Sampling Locations for CY-1982



W-62 Formerly V (Village Well)

1982

3.1.1 Muons

Coincidence electronics associated with the scintillation counters in the MERL was used to determine the direction and radiation levels of the penetrating radiation (muons). Information on the expected arrival time and intensity of the particles, based on the accelerator operation, was sent to MERL via transmitter to aid in the measurements. Dose measurements were made at the site boundary with the scintillation counters while recording the number of counts from one of the 110 liter ionization chambers placed in the path of the muons much closer to the source. The counts from that ionization chamber were recorded for the entire year through the data logger and the natural background subtracted to determine the annual dose at the site boundary. Muons from the Neutrino Area in CY-1982 resulted in negligible exposures, primarily because the Muon Laboratory was not conducting a muon experiment.

Measurements of muons from the Proton Area (Fig. 3) which were made in CY-1980 with 350 GeV protons were repeated in CY-1981 with 400 GeV protons.[11] Measurements were made both on and off the site. Also, radiation surveys were made using hand-held survey instruments close to the source. In CY-1982 the radiation surveys close to the source were repeated and agreed with the CY-1981

measurements. The site boundary muon dose rate for CY-1982 was then determined from the CY-1981 measurements and the number of protons incident on the targets. The fence line annual dose based on 24 hour per day occupancy was 0.1 mrem for CY-1982 for the Proton Area.

Based on the CY-1981 measurements the fence line annual maximum doses for CY-1982 were 0.2 mrem for the Meson Area and negligible for the Neutrino Area, assuming 24 hour per day occupancy.

3.1.2 Neutrons

Neutrons penetrated the shielding in the most easterly of the external experimental areas (Proton East) in the vicinity of the primary target (Fig. 3) in the Proton Area again in CY-1982.[7,12] The fence line maximum dose at the site boundary from these neutrons was 0.08 mrem for CY-1982, based on 24 hour per day occupancy. On-site exposures were kept low by fencing the areas having measurable dose rates and excluding the public from these areas. The neutrons originated in a secondary beam dump used to stop high energy neutral particles. The latter were obtained from the primary target and used to produce electromagnetic radiation for a particular experiment.

3.1.3 Gamma Rays

The primary radioactive waste storage area on site - the Boneyard - is also the primary source of off-site gamma radiation. As shown in Fig. 1, this area lies close to the site boundary. On the north side there is an earth berm to prevent any direct radiation from leaving the site. Shielding has been provided above and on all sides of those radioactive materials which would produce high radiation levels without shielding. This was done to protect Fermilab workers as well as reduce the off-site dose. The items responsible for most of the site boundary dose rate in the past[7] were disposed of in an approved off-site burial ground in late CY-1979. Most of the remaining inventory was shipped in CY-1982. Radiation levels at the site boundary closest to the Boneyard were at background levels in CY-1982.

3.2 Airborne Radioactivity

Radioactivation of air in measurable concentrations will occur wherever the proton beam or the spray of secondary particles resulting from its interactions with matter passes through the air. Along most proton beam lines (paths of the protons from the accelerator) the protons travel inside evacuated pipes. Thus, radioactivation of air

is now usually caused by secondary particles. Monitoring of such activation is carried out for purposes of personnel exposure control. Under no circumstances is the off-site concentration of airborne radioactivity expected to approach the limits for uncontrolled areas.

Radioactive gas, primarily ^{11}C, was produced by interaction of secondary particles with air. Monitoring was carried out by detecting the beta particles emitted in the radioactive ^{11}C decay. A release of 1.05 kCi occurred from the labyrinth stack (Airborne Effluent Release Point in Fig. 3) in the Neutrino Area during 1982. From measurements made at the stack and calculations based on a Gaussian plume diffusion model,[13] the expected dose at the site boundary for 1982 was 0.2 mrem, which corresponds to 0.04 percent of the applicable Concentration Guide[14] (Section 5).

A debonding oven was placed in operation in CY-1979 (near W43 in Fig. 4). Its purpose is to debond magnets by decomposing the epoxy adhesives at high temperatures. Most of these magnets are radioactive, having failed during accelerator operations. The gaseous effluent was measured during the acceptance test on June 8, 1979 conducted for the Illinois EPA and contained only ^{3}H at very low levels. The test utilized a typical 6 m (20 ft) long magnet reading 0.8 mrem/hr at 0.3 m (1 ft) from the surface and 8 mrem/hr

in the bore tube where the protons traveled. The total amount of ^{3}H released from this magnet was 160 μCi at a stack concentration of 1.3×10^{-8} μCi/mℓ or about 20 percent of the Concentration Guide (Section 5) corresponding to 500 mrem per year. The stack is approximately 10 m (30 ft) high. Using the Gaussian plume diffusion model[13] with neutral wind conditions[15] gives a negligible percentage of the applicable Concentration Guide at the site boundary. Thirty magnets were debonded in CY-1982 and the total tritium release from this stack was approximately 5 mCi.

A water evaporator was placed in operation in CY-1981 at the Boneyard (Figure 1) to dispose of tritiated water collected from closed loop cooling systems. In CY-1982 a total of 8400 ℓ (2200 gal) of water containing a total of 58 mCi of ^{3}H was evaporated. The average concentration at the site boundary was less than 0.01 percent of the Concentration Guide[2] (Section 5) using the Gaussian plume diffusion model[13] with neutral wind conditions.[15] Soil and vegetation samples were also taken. See Sections 3.3.2.3 and 3.3.3.

3.3 Waterborne Radioactivity

During accelerator operations, some radioactivation of the soil will occur.[16,17] Leaching of these radionuclides into the ground water provides a possible mechanism for transport of Fermilab-produced radionuclides into the surface run-off waters and aquifer. Hence, a broad program of ground water monitoring for radioactivity is maintained. Measurements are also made of on-site concentrations of radionuclides in Fermilab surface waters and in closed loop (recirculating) cooling systems which are sources of potential off-site releases.

Water samples are collected periodically on site and from surface waters off site. They are analyzed for the presence of those radionuclides which are produced in and leachable from Fermilab soils in measurable quantities.[17] This group of radionuclides also includes those produced in water directly. Analyses are made for ^{3}H, ^{7}Be, ^{22}Na, ^{45}Ca, ^{54}Mn and ^{60}Co. The latter is hardly leachable (approximately 0.1 percent); however, it has been detected in discharges during regeneration of water treatment resin.

Water samples were collected from the following types of wells on site:

1. Farm Wells - Approximately 30 m Deep - 37 Samples

2. Fermilab Water Supplies - Approximately 70 m Deep - 4 Samples

3. Fermilab Deep Well Emergency Supply - 436 m Deep - 1 Sample

Water samples were also collected from sumps, creeks, and rivers. All surface and ground water samples collected between January 1, 1982 and September 30, 1982 were analyzed by Eberline Instrument Corp., Midwest Facilities, 245 Roosevelt Road, West Chicago, Illinois 60185. Those collected after September 30 were analyzed by Hazelton Environmental Sciences, 1500 Frontage Road, Northbrook, Illinois 60062. Each monthly shipment included at least one sample containing accelerator-produced radionuclides in known amounts to check the accuracy of the assays. See Section 4.

3.3.1 Water Sample Collection

Water samples collected from wells not in regular use are pumped for a sufficient length of time to insure that the water standing in the pipe has been pumped out before a sample is taken. The water in the pipe could conceivably

have been there since the last time a sample was taken. Normally, the pipe volume is pumped several times before sampling. Water samples from sumps, creeks and other surface waters are normally collected by dipping a bottle well below the surface. Several of the sumps inside normally locked enclosures are sampled by remotely operated peristaltic pumps or the sump pumps themselves.

The water sampling schedule is based on the following rationale:

1. Wells 38/39*, 43, 49, & 78 are sampled quarterly because they are closest to the areas of maximum soil activation (near targets and dumps) and are in the direction the water would flow in the aquifer.

2. Wells 1, 5, 17A, 20, and 45 are sampled semiannually because they are near the accelerator.

*38 and 39 are close to each other and sampled the same region of the aquifer. Each is sampled semiannually. See Figure 4.

3. The other wells are sampled annually because they are near the site boundary or serve as back-ups to the other wells or as drinking water supplies.

4. The one deep well is sampled annually to look for long-term trends or changes in percolation down to that level.

5. The MF5, N1, N2, and PW8 sumps are sampled bimonthly because they are the closest to the areas of maximum soil activation. See Figure 3.

6. The MF4 sump and the N1 Retention Pit are sampled quarterly because the MF4 sump collects water from a region with less activity than that of the MF5 sump (outside the impervious membrane instead of inside) and the N1 Retention Pit does not have a pump in it even though it collects from a region of higher activity than the N1 sump.

7. The other sumps are sampled less frequently with the frequency based on the tritium concentration found there in the past.

8. The creeks are routinely sampled three times a year and Kress Creek is sampled monthly whenever water

from the Laboratory flows over the spillway into the creek.

9. Ponds and ditches with a potential for receiving radioactive water are sampled annually.

10. The Fox River and west branch of the DuPage River which receive run-off from Fermilab are sampled annually.

11. The closed loop cooling systems which cool targets and dumps are sampled with a frequency which depends on the level of radioactivity. Operating systems having concentrations greater than 0.01 μCi/mℓ are sampled quarterly. Those having concentrations between 0.001 and 0.01 μCi/mℓ are sampled semiannually. Those between 0.00001 and 0.001 μCi/mℓ are sampled annually.

12. The resin regeneration systems are routinely sampled for analysis by an outside laboratory semiannually. Analyses are performed on site for samples from every regeneration sending radioactive effluent to the CUB tile field inside the Main Ring.

13. Several samples are collected annually to look for radioactivity leached from steel.

3.3.2 Results of Analyses

The Fermilab CY-1982 water sampling locations for detection of accelerator-produced activity are shown in Figs. 3, 4, and 5. No accelerator-produced radionuclides were reported in water samples taken from the three creeks leaving the site (Fig. 5). Three samples were obtained from each of the three creeks leaving the site: Kress Creek, Ferry Creek, and Indian Creek. River water samples were obtained once during CY-1982 from the Fox River in Aurora and from the west branch of the DuPage River in Warrenville. Neither river is utilized as a drinking water supply. No evidence for accelerator-produced radionuclides was found.

The Village water supply (W62 in Fig. 4) is the Laboratory's only community water supply. Quarterly water samples were collected and a composite analyzed for naturally occurring as well as reactor and accelerator-produced radionuclides in CY-1980. No activity was found using very low detection limits. See Section 5. The same was true for composite samples from Fermilab's other two drinking water systems providing water to more than 25 persons a day. These (W1, with W3 as back-up, and

W55 in Fig. 3) supply water to Wilson Hall (formerly called the Central Laboratory) and to Site 55 and the east side of the main accelerator (Main Ring). These drinking water systems received annual routine sampling in CY-1982. No accelerator-produced radionuclides were detected in the 42 samples taken from all on-site wells monitored in CY-1982.

3.3.2.1 Tritium

The results for on-site tritium measurements yielding detectable levels in surface waters (Fig. 3) are given in Table 1. All other sampling points were essentially at background levels (Figs. 3 and 5). The sumps collect waters from around the footings of the buildings and enclosures. This water is considered surface water. Only aquifers are called ground waters. The total off-site release in surface waters was 530 mCi of tritium this year compared with 655 mCi last year. This decrease was primarily because less surface water left the site in CY-1982.[7] See Table 2. The release occurred at less than 0.3 percent of the Concentration Guide (Section 5) and made a negligible contribution to the potential off-site dose.

TABLE 1

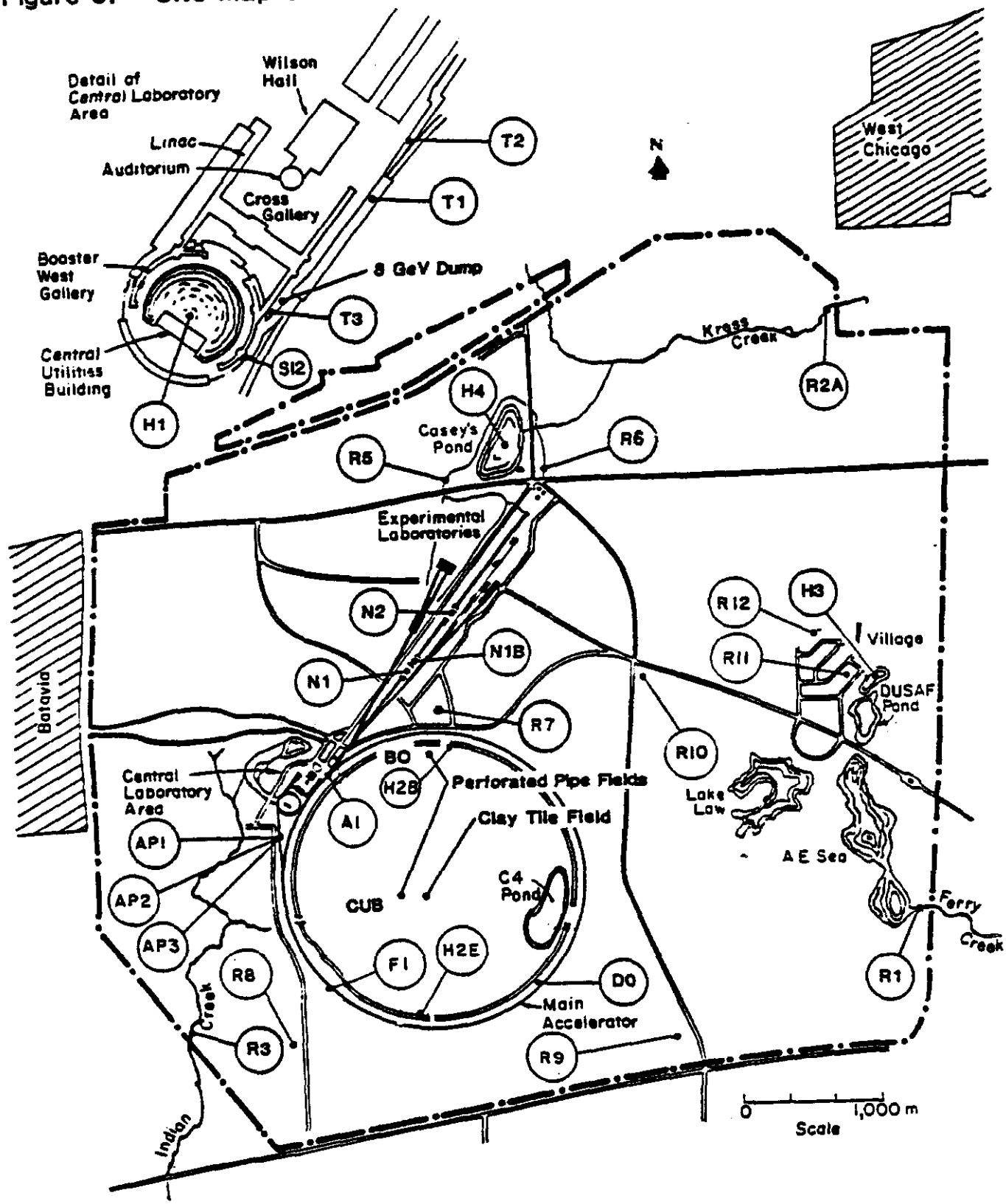
Tritium Detected in On-Site Water Samples

Tritium Concentration C (μCi/mℓ)*

Collection Point	Number of Samples	C Max	C Max Error	C Min	C Min Error	C Mean	Percent of Standard
MF4 Sump	5	2.3×10^{-4}	5.0×10^{-6}	1.7×10^{-5}	1.6×10^{-6}	1.0×10^{-4}	3.3
MF5 Sump	10	1.3×10^{-4}	4.0×10^{-6}	5.3×10^{-5}	5.0×10^{-6}	7.6×10^{-5}	2.6
G6 Sump	1	5.4×10^{-6}	5.0×10^{-7}	5.4×10^{-6}	5.0×10^{-7}	5.4×10^{-6}	0.2
G7 Sump	3	4.3×10^{-5}	4.0×10^{-6}	4.1×10^{-6}	1.1×10^{-6}	1.7×10^{-5}	0.6
N1 Sump	9	3.0×10^{-4}	3.0×10^{-5}	6.2×10^{-5}	6.0×10^{-6}	1.6×10^{-4}	5.2
N1B Sump	2	8.0×10^{-6}	8.0×10^{-7}	5.7×10^{-6}	1.1×10^{-7}	6.8×10^{-6}	0.2
N2 Sump	9	2.0×10^{-4}	2.0×10^{-5}	4.7×10^{-5}	5.0×10^{-6}	1.4×10^{-4}	4.5
PE3 Sump	3	6.9×10^{-6}	7.0×10^{-7}	< 1.2	-------	$<3.2 \times 10^{-6}$	0.1
PE4 Sump	2	7.2×10^{-6}	7.0×10^{-7}	5.1×10^{-6}	1.1×10^{-6}	6.2×10^{-6}	0.2
PCW Sump	2	9.4×10^{-6}	9.0×10^{-7}	1.5×10^{-6}	9.0×10^{-7}	5.5×10^{-6}	0.2
PW6 Sump	1	5.0×10^{-6}	1.1×10^{-6}	5.0×10^{-6}	1.1×10^{-6}	5.0×10^{-6}	0.2
PW8 Sump	6	1.5×10^{-5}	1.5×10^{-6}	4.6×10^{-6}	1.1×10^{-6}	7.6×10^{-6}	0.3
PW9 Sump	2	1.3×10^{-4}	1.0×10^{-5}	1.5×10^{-5}	1.5×10^{-6}	5.4×10^{-5}	1.7
N2 B Sump	2	6.0×10^{-6}	6.0×10^{-7}	< 1.2	-------	$<3.5 \times 10^{-6}$	0.1
G 4 Sump	1	2.6×10^{-4}	3.0×10^{-5}	2.6×10^{-4}	3.0×10^{-5}	2.6×10^{-4}	8.6
G 5 Sump	1	1.7×10^{-4}	2.0×10^{-5}	1.7×10^{-4}	2.0×10^{-5}	1.7×10^{-4}	5.6
D O Sump	2	1.8×10^{-5}	2.0×10^{-6}	1.9×10^{-6}	1.0×10^{-6}	1.0×10^{-5}	0.3

*C max is the highest concentration detected in any sample from that location and C min is the lowest. C mean is the average for all samples from one location.

Figure 5. - Site Map of Surface Water Sampling Locations for CY-1982



Legend :

Sumps = S, T, D, E, N, and AP
Ponds = H
Ditches = R

1912

The relatively high tritium concentrations reported for sumps G4 and G5 in the Neutrino Area Target Service Building (TSB) are believed to have resulted from the release of small volumes of closed-loop cooling water shortly before the samples were taken. A small quantity of cooling water spills out when a set of magnets is separated for storage or repair work. Detailed reports of off-site effluent releases and on-site discharges are made via the Department of Energy Effluent and On-Site Discharge Information Systems, EG&G, Idaho, Inc., P.O. Box 1625, Idaho Falls, Idaho 83401.

The surface water from the experimental areas flows into Casey's Pond except during wet seasons. Then, the pond fills up and barricades are placed at the two entrances to the pond to keep the water from flooding the pump room. When these barriers, called stop logs, are in place, the water bypasses the pond and leaves the site via Kress Creek. This was the case for one-third of the year in 1982.

No unplanned tritium releases occurred in CY-1982.

3.3.2.2 Beryllium

Concurrent with the production of ^{3}H with 12 year half-life is the production of ^{7}Be with 53 day half-life in the closed cooling water systems. The ^{7}Be is chemically

active and is easily removed from the water by the resins used to maintain water purity. These resins are regenerated in two separate systems located at the Central Utilities Building (Fig. 5). The ^{7}Be is precipitated out of the Main Ring system regeneration effluent, is allowed to decay until the residue is at a concentration below that permitted for community water systems and is disposed of as industrial process waste. The discharge from the other system, which regenerates resin from the small tanks used throughout the site, is sent to a clay tile field inside the main accelerator (Fig. 5). There it percolates into the soil about 60 cm (2 ft) below the surface. The short half-life of ^{7}Be and its strong chemical affinity with the soil ensure that the release will place no burden on the environment. The total amount of ^{7}Be discharged to the tile field in CY-1982 was 230 mCi.

Silt and vegetation samples were taken near discharge points for radioactive effluents and at the points where the three creeks leave the site. The results for silt samples are given in Table 2. The vegetation results are given in Section 3.3.3

TABLE 2

Silt Sampling Results for CY-1982

Location	Radionuclides	Concentration (pCi/g)
Boneyard (Adjacent to Evaporator)	^{7}Be	390 ± 40
	^{22}Na	140 ± 13
	^{54}Mn	1560 ± 140
	^{57}Co	2140 ± 190
	^{60}Co	1220 ± 110
	^{65}Zn	470 ± 40
	Additional	< 140
DO Sump Discharge Area at Main Ring Pond	No Accelerator-Produced Activity	
Ferry Creek (R1)	No Accelerator-Produced Activity	
Indian Creek (R3)	No Accelerator-Produced Activity	
Kress Creek (R2A)	No Accelerator-Produced Activity	
Meson Area Spur Track (W78)	^{7}Be	150 ± 15
	^{46}Sc	590 ± 40
	^{51}Cr	1590 ± 110
	^{54}Mn	2180 ± 150
	^{56}Co	130 ± 9
	^{60}Co	150 ± 11
	^{59}Fe	230 ± 16
	Additional	< 130
MF5 Sump Discharge Area	^{7}Be	14 ± 1
N1 Sump Discharge Area	^{7}Be	65 ± 5
	^{22}Na	7 ± 1
	^{54}Mn	79 ± 6
N2 Sump Discharge Area	^{7}Be	2.1 ± 0.4
	^{22}Na	1.8 ± 0.1
	^{54}Mn	0.6 ± 0.1
	^{65}Zn	0.7 ± 0.1
PW8 Sump Discharge Area	^{22}Na	0.1 ± 0.02
	^{54}Mn	0.1 ± 0.02
T3 Sump Discharge Area at Main Ring Pond (A0 Ditch)	^{22}Na	4.5 ± 0.3
	^{54}Mn	2.0 ± 0.1

3.3.2.3 Other Radionuclides

Contamination of surface soil was found in two locations in CY-1982. The principal radionuclide was ^{54}Mn in the Meson Area at the Target Train spur track (near W78 in Fig. 3). The train track is a narrow gauge line similar to those used in mining operations. The radioactivity is believed to have come from removable contamination associated with Target Train components. These steel components are taken off the train flat cars at the location where the contamination was found. Hence, the loose material, probably rust and paint chips, fell off during the unloading process. The ^{54}Mn concentration was approximately 2 nCi/g. Some soil was removed for off-site disposal in CY-1982. Some activity still remains.

The second location where radioactive surface soil was found was adjacent to the evaporator at the Boneyard (Fig. 1). In this case the principal radionuclide was ^{57}Co and the concentration was approximately 2 nCi/g. The contamination occurred during the filling of the evaporator. This activity has not yet been removed for disposal.

Tests were also made for radium and thorium in our deep well (W4 in Fig. 4) to look for any long-term changes in percolation rates to deep-lying aquifers. The results were

consistent with no changes, as has been the case in the past.

3.3.3 Vegetation Sampling

An annual vegetation sampling program was initiated in CY-1978. In CY-1982 a vegetation sample was taken near the ^{11}C exhaust in the Neutrino Area (Fig. 3). A soil sample was also taken near the exhaust. See Section 3.3.2.2. Vegetation samples were taken in the vicinity of discharges from sumps collecting water in areas having the most soil activation. This soil activation resulted from direct interactions of the primary protons or the secondary particles they produce. In addition, a vegetation sample was taken next to the evaporator in the Boneyard where ^{3}H from closed loop systems is disposed of by release to the atmosphere.

The peak concentrations for vegetation sampling are based on the weight of the unprocessed sample. From previous results[7] the radionuclide ^{7}Be is expected to be present as surface contamination while ^{22}Na and ^{60}Co are most likely incorporated into the plants. Vegetation near sump discharges was analyzed for cases where accelerator-produced radionuclides were found in the silt. See Table 2. The results from the analyses of the

vegetation samples are given in Table 3. The vegetation contained small quantities of ^{7}Be, even those samples taken adjacent to the creeks near the site boundaries. Since the half-life of ^{7}Be is 53 days and since these samples were taken long after the 1982 accelerator operations were terminated, the results near the site boundaries are believed spurious and not related to Fermilab operations. The corresponding silt samples taken near the site boundary did not contain ^{7}Be. See Table 2.

The vegetation sample from the vicinity of the N1 Labyrinth Stack was analyzed for ^{3}H this year. The result was 646 pCi/mℓ in the water removed by heating the sample. The presence of ^{3}H is to be expected since ^{3}H is produced, as well as ^{11}C, by the spallation of air.

3.3.4 Soil Activation

Since the percolation rates for water in Fermilab soils are calculated to be very low - less than 1 m (3 ft) per year[18] - analyses of well waters do not provide the early warning desired for detection of accelerator-produced radioactivity in the ground water. To provide such a warning soil samples were taken from the vicinity of targets and other locations where proton interactions result in some radioactivation of the soil.

TABLE 3

Vegetation Sampling Results

Location	Radionuclides	Concentration (pCi/g)
Boneyard	^{3}H	56 ± 6
DO Sump Discharge Area at Main Ring Pond	^{7}Be	7 ± 1
Ferry Creek	^{7}Be	8 ± 2
Indian Creek	^{7}Be	4.2 ± 0.9
Kress Creek	^{7}Be	6.4 ± 0.8
MF5 Sump Discharge Area	^{7}Be ^{22}Na ^{54}Mn	13 ± 1 2.2 ± 0.2 1.3 ± 0.1
N1 Sump Discharge Area	^{7}Be ^{22}Na ^{54}Mn	13 ± 1 14 ± 1 8 ± 1
N1 Labyrinth Stack	^{3}H ^{7}Be ^{22}Na ^{54}Mn	646 ± 11 20 ± 2 0.4 ± 0.2 0.4 ± 0.2
N2 Sump Discharge Area	^{7}Be ^{22}Na	9 ± 2 5.3 ± 0.4
PW8 Sump Discharge Area	^{7}Be	12 ± 1
T3 Sump Discharge Area at Main Ring Pond (AO Ditch)	^{7}Be ^{22}Na ^{54}Mn	11 ± 1 4.3 ± 0.3 0.9 ± 0.1

Many radionuclides were detected but since the major long-lived ones leachable from Fermilab soils were ^{3}H and ^{22}Na, quantitative measurements were made only on those.[16] The results have been presented elsewhere.[7,19]

3.4 Nonradioactive Pollutants

3.4.1 Airborne Effluents

A magnet debonding oven in the Industrial Building complex (W43, Fig. 4) was placed in operation in CY-1979, and was used to debond 30 magnets in CY-1982. It consists of an electrically heated oven operating at 450°C (850°F) with a propane fired afterburner operating at $\geq$760°C (1400°F) to assure complete oxidation of all combustion products.

This debonding oven was installed under a construction permit issued by the Illinois Environmental Protection Agency (IEPA). A fully documented acceptance test of emissions, including particulates, NO_x and hydrocarbons, was performed by the Almega Corporation and IEPA has granted an operating permit. The debonding process removes approximately 57 kg (125 lb) of cured bonding epoxy from each magnet.

3.4.2 Water Utilization

3.4.2.1 Domestic Water Supplies

The domestic water supply at Fermilab is essentially provided by two wells pumping from an aquifer approximately 70 m (220 ft) deep. One (W1 in Fig. 4) is located in the

Central Laboratory area and the other (W62 in Fig. 4) supplies the separate Village system. A third well (W3 in Fig. 4) pumps from the same aquifer and supplies water to the Main Site System when demand exceeds the capacity of W1.

These wells have chlorination systems and our water laboratory tests for pH and fecal coliform monthly. The chlorine level in the chlorinated drinking water supplies is tested each work day. Test results conformed to Illinois standards during 1982, except for one test of drinking water from W62 which contained no chlorine. No coliform was found and the empty chlorine bottle was replaced the same day. Our average use from these wells was approximately 360,000 ℓ/day (95,000 gal/day), an increase from 1981, but less than in 1980.

3.4.2.2 Industrial Water Ponding Systems

There are several water systems used for cooling magnets and for fire protection:

The Industrial Cooling Water (ICW) System consists of Casey's Pond (H4 in Fig. 5) at the end of the Neutrino Beam Line and underground mains to fire hydrants and sprinkler systems throughout the Main Site and Wilson Hall.

Casey's Pond is supplied by surface drainage and can also be supplied by pumping from the Fox River. The pond, holding 68,000,000 ℓ (18,000,000 gal) is accessible to the public.

The Swan Lake/Booster Pond System (H1 in Fig. 5) is used for cooling purposes at the Central Utilities Building (C.U.B.). Water is pumped from the Booster Pond into a ditch in which it runs by way of a small West Pond into Swan Lake. The water is then returned to the Booster Pond by a return ditch. Water is also pumped from Swan Lake to N1 Service Building for cooling purposes, from which it returns by a surface ditch. This system can be supplied water from the ICW System and it overflows into Indian Creek.

The Main Ring Ponding System consists of a series of interconnecting canals completely encircling the interior of the Main Ring with a large reservoir pond at C4 (Fig. 5). This water is used in heat exchangers at the Service Buildings for cooling the Main Ring magnets. The system is generally supplied by surface drainage, although make-up water can be pumped from Casey's Pond. The system overflows into Lake Law (Fig. 5). The public is excluded from the area inside the Main Ring, and hence the Main Ring Ponding System, when the accelerator is in operation. The water in these systems normally meets the quality requirements of

water in general use in Illinois (Section 5). There was an exception to this during spraying of the Main Ring Ponding System with copper sulfate in CY-1981. No copper sulfate was applied in CY-1982.

3.4.2.3 Other Lakes and Ponds

Surface drainage from the eastern portion of the site flows into Lake Law, DUSAF Pond and the AE Sea (Fig. 5). The chlorinated effluent from the Village sewage treatment plant oxidation pond (H3 in Fig. 5) also flows into DUSAF Pond. These lakes and ponds are accessible to the public, and they are the head waters of Ferry Creek.

3.4.2.4 Tests for Pollutants

Semi-annual tests are made of water samples taken where the three creeks leave the site (Fig. 5), as well as from Casey's Pond and the Fox River. Results for 1982 are found in Table 4. Tests for fecal coliform bacteria are made monthly in our water laboratory.

TABLE 4

Site Wide Water Quality Report for CY-1982

	pH		DO mg/ℓ		DO5 mg/ℓ		Susp. Solids mg/ℓ		Fecal Coliform mg/ℓ	
	April	Sept.	April	Sept.	April	Sept.	April	Sept.	April	Sept.
Ferry Creek	---	8.6	12.4	6.4	---	7.9	51	123	0	2
Kress Creek	8.0	7.8	12.2	6.0	2.1	8.4	5	10	2	200
Indian Creek	7.8	7.9	12.2	6.5	2.8	4.3	15	44	70	175
Casey's Pond	8.4	8.6	13.4	8.9	5.9	8.8	27	11	2	1
Fox River	8.4	8.5	12.0	8.0	4.9	7.8	13	36	150	59
General Standards[22]	6.9 - 9.0		Not less than 5.0 at any time		**		**		Mean of 200	

*Inaccessible
**There are standards for effluent from treatment works or waste water sources, but no general standards.

3.4.3 Sewage Treatment

An authorization permit to discharge under the National Pollutant Discharge Elimination System (NPDES) has been obtained for the Village Oxidation Pond (H3 in Fig. 5).[22] Monthly testing results for 1982 are in Table 5.

The Main Site sewer system was hooked into the City of Batavia system June 26, 1979 and has been delivering sewage to the Batavia sewage treatment plant since that time.

The NPDES permit[21] for the Village sewer system was renewed by IEPA in 1979 and the limits for 30 days average BOD5 and suspended solids were reduced from 30 mg/ℓ and 37 mg/ℓ to 10 mg/ℓ and 12 mg/ℓ, respectively. Subject to the limits of the new permit, the Village system exceeded the limits for suspended solids five times in CY-1982, in spite of treatments with Aquazine to control algae. In January and February 1982, the effluent release was halted each month for the entire month. See Table 5. The limit for BOD5 was exceeded twice.

TABLE 5

Village Sewage Treatment Plant

Monthly Averages Report for CY-1982

Parameter	Permit Limit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
pH	6-9	No Release	No Release	7.7	8.4	8.3	7.5	7.6	7.8	7.6	**	8.1	8.3
BOD5 mg/ℓ	10	No Release	No Release	14.4*	10.0	2.0	1.5	5.0	3.7	4.0	**	12.2*	8.6
Suspended Solids mg/ℓ	12	No Release	No Release	10.5	21*	8.5	15*	16*	9.0	8.5	**	38.5*	24.5*
Fecal Col. #/100 mℓ	400				0	0	0	0	0	0	**	0	1

*Violation Report filed
**Not sampled

3.4.4 Chemical Treatment of Water Systems

Some chemical treatment of our various water systems is required each year to control the growth of algae and aquatic weeds. Only EPA registered agents are administered by trained personnel following the manufacturer's directions.

3.4.4.1 Dalapon

Dalapon was used to treat drainage ditches for control of cattail (Typha sp.) growth. Applications were made to ditches in the external experimental areas and along the Main Ring Road inside the main accelerator. A total 329 kg (725 lb) was applied to an estimated 34 km (21 mi) of drainage ditches.

3.4.4.2 Diquat

Diquat has been used to treat the Main Ring cooling ponds for control of duckweed (Lemna minor sp.) in the past. None was applied in CY-1982.

3.4.4.3 Chlorine

In addition to the routine chlorination of the domestic water systems, the swimming pool and the Village Oxidation Pond, a chlorination system for the Swan Lake cooling pond system has proved successful in helping to eliminate the need for chromate treatment of the cooling towers. Chlorine is added to the cooling water for a period of 30 minutes four times a day at a rate which results in a chlorine concentration of 0.5 ppm as the cooling water leaves the equipment.

3.4.4.4 Aquazine

As previously mentioned, it was necessary to treat the Village Oxidation Pond to control algae growth and reduce suspended solids. The pond was treated a total of four times in CY-1982, following the manufacturer's application instructions. The quantity of Aquazine used three of the four times was 136 kg (300 lbs). The other time the quantity was 91 kg (200 lbs).

3.4.5 Heavy Metals and Other Toxic Materials

The continued success of the Swan Lake cooling pond system again made it possible to eliminate the use of chromates in 1982. Although it was necessary to use the cooling towers during the warm summer months, it was not necessary to treat the towers with chromate compounds. The chlorinated Swan Lake cooling pond water was passed through the cooling system and a biodispersant, Nalco 7348, was added which lifted deposits from the metal surfaces so they could be oxidized by the chlorine. The rate of application was 3.6 kg (8 lbs) per day with a peak concentration of 20 mg/ℓ. Nalco 7348 is a polyglycol manufactured by Nalco Chemical Company, 2901 Butterfield Road, Oak Brook, Illinois 60521. Another Nalco product, Nalco 7387, was applied continuously at less than 1 mg/ℓ. The rate of application was the same per day as for Nalco 7348. Nalco 7387 is an organophosphorus compound which prevents scale formation. It does not have the toxic properties of organic phosphorus esters found in some restricted-use pesticides.[22]

Soil borings were made in the old CUB perforated pipe field and the new CUB clay tile field (Fig. 5), and soil samples collected between 30 cm (1 ft) and 150 cm (5 ft) approximately below the surface. These samples were

analyzed for hexavalent chromium, zinc, copper, lead, chloride, and sulfide by Environmental Research Group, Inc., 7303 West 90th Street, Bridgeview, Illinois 60455. A background sample was collected near Well 45 (W45 in Fig. 4). The results are shown in Table 6. It is clear that some zinc and copper are being deposited in the new tile field. These are slowly moving downward. The chlorides which are soluble are moving downward at a much more rapid rate. See Sections 3.5.3.4 and 3.5.3.5 for discussions of potential environmental impacts. The heavy metals and chlorides are in the effluent from the regeneration of water treatment resins. The heavy metals are removed from the water systems by the resins. The chlorides come from the use of hydrochloric acid to regenerate the resins.

No chromate has been discharged into the new CUB tile field. The results reported in Table 6 are at the detection level and are believed spurious.

TABLE 6

Soil Sampling Results for Samples Taken Below the CUB Fields

Pollutant	Approximate Sampling Depth (cm)	CUB Perforated Pipe Field Concentration* (mg/kg)	CUB Clay Tile Field Concentration* (mg/kg)
Zinc	50	0	550
	75	0	280
	100	0	140
	125	0	140
Copper	50	0	42
	75	7	24
	100	0	12
	125	0	4
Lead	50	0	1
	75	1	0
	100	0	0
	125	0	0
Chloride	50	0	30
	75	10	110
	100	0	170
	125	20	390
Sulfate	50	61	81
	75	16	141
	100	4	71
	125	0	391
Hexavalent Chromium	50	0	0
	75	0	0.55
	100	0	0.55
	125	0	0.55
			0.14

*Background Subtracted

Water samples were collected from Well 20 and Well 45 (Fig. 4). The samples were copper, hexavalent chromium, chloride, and sulfate. No copper or chromium was found (<0.05 ppm). Chloride in Well 20 was 3.9 ppm and in Well 45 was 5.1 ppm. Sulfate was 34 ppm in Well 20 and 62 ppm in Well 45. Thus, there was no evidence for high concentrations in the aquifer.

There were no ethylene glycol spills in CY-1982.

Sampling of silt and run-off water was done in CY-1982 for fields, ditches, and ponds treated with pesticides. The locations sampled were R8, R9, R10, R11, and R12 in Fig. 5. Analyses were made for seven pesticides including 2,4D. The detection limit for the pesticides was 10 ppm. Aquazine and Roundup were found at approximately 1500 ppm. Aquazine was detected in the effluent from the Village Oxidation Pond. Roundup was found in a soil sample taken near one of the houses in the Village. Residues of all other pesticides were below the detection limit. The analyses were performed by Gabriel and Associates, 1814 North Marshfield, Chicago, Illinois 60622.

3.5 Environmental Impact

3.5.1 Assessments of Potential Radiation Dose to the Public

Fermi National Accelerator Laboratory is located in the densely populated Chicago Area. There are about eight million people living within 80 km (50 mi) of the site.[23] There are 326,645 people within 16 km (10 mi) of the center of the main accelerator based on the 1980 census results compared to 265,677 counted in the 1970 census. The detailed distribution of population as a function of distance and direction from Fermilab is given in Table 7.[23] The population distribution close to Fermilab is shown in Figure 6.

The dose rate at the site boundary from Fermilab operations was primarily from radioactive gas (^{11}C), leaving the Neutrino Area labyrinth stack and muons from the Meson Area. Neutrons also contributed. The distributions of neutrons and radioactive gas were assumed to be isotropic while measurements of muons showed they went in one direction (toward the northeast). The maximum annual dose rate at the site boundary and the annual dose to the off-site individual receiving the maximum dose from Fermilab operations are essentially the same since the change in distance is small to the site boundary to off-site housing compared to the change in dose rate with

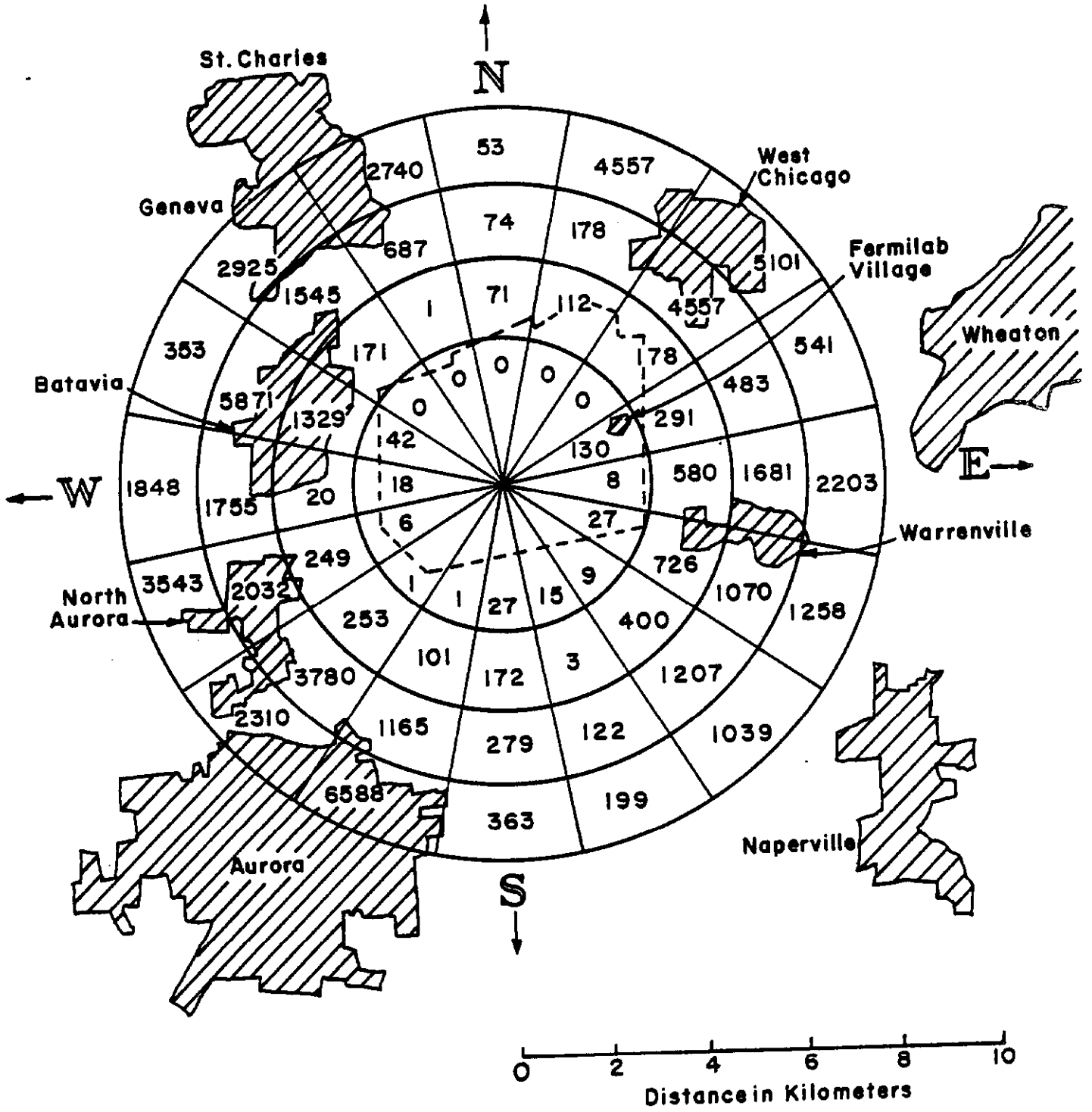


Figure 6. Population Distribution in the Vicinity of Fermilab

TABLE 7

Incremental Population Data in Vicinity of Fermilab, 1980

LATITUDE = 41.832 LONGITUDE = 88.251

DISTANCE, KILOMETERS FROM CENTER OF MAIN RING	0-8	8-16	16-32	32-48	48-64	64-80	80-97	97-113	113-128
DISTANCE, MILES	0-5	5-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80
DIRECTION									
N	198	1110	77247	75658	63188	37183	30696	28459	149892
NNE	3455	5821	68274	76075	120930	145415	100858	173092	87495
NE	9836	12718	78701	292724	139718	0	0	0	0
ENE	1445	63784	263526	840460	551913	0	0	0	0
E	4472	18423	218631	1107254	924752	0	0	33317	56442
ESE	3081	15075	92242	268040	597113	379986	196888	78056	17600
SE	2655	25167	37956	34405	106938	38944	24651	11963	10027
SSE	339	3262	44203	148699	7962	21154	70503	10828	13195
S	841	1336	8604	10301	17011	11089	6640	4354	11967
SSW	7055	49656	8635	3492	17420	6373	25217	24588	10469
SW	6344	35851	13598	15566	5317	30917	36362	13671	13226
WSW	5030	2205	5578	6322	4509	10930	8474	11704	12175
W	3641	971	2941	5339	5111	13693	8445	28768	49103
WNW	7595	851	3018	42762	6723	21231	40449	13891	37012
NW	4641	9607	3297	7974	7358	65288	157549	71682	28229
NNW	3428	15152	22722	10674	29830	17952	29399	24276	58430
TOTAL	65656	260989	949171	2945745	2605793	800155	736131	528649	555262
CUMULATIVE TOTAL	65656	326645	1275816	4221561	6827354	7627509	8363640	8892289	9447551

distance. The total dose to the individual is 0.5 mrem for CY-1982. Airborne radioactivity contributed 0.2 mrem, neutrons 0.1 mrem, and muons 0.2 mrem. The point where that exposure occurred is along the path muons traveled which originated in the Meson Area.

The radiation exposure to the general population from operation of Fermilab in CY-1982 was about 3 person-rem. Approximately 1.6 person-rem was from neutrons and approximately 0.7 person-rem was from airborne radioactivity (^{11}C). The exposures are given in Table 8. This is to be compared with a total of approximately one million person-rem to the population within 80 km (50 mi) from natural background radioactivity.[23,24] Radiation from diagnostic x-rays, medical treatments, and other artificial sources accounted for about 500,000 person-rem in CY-1982.[24]

TABLE 8

Summary of Population Exposures for CY-1982
Within an 80 km (50 mi) Radius of Fermilab

Source	Contributions to Population Exposures (person-rem)
Penetrating Radiation from Proton Area	1.7
Penetrating Radiation from Meson Area	0.2
Airborne Radioactivity from Neutrino Area	0.7
TOTAL	2.6

Since the neutrons are assumed to be distributed isotropically and the muons are known to all travel in approximately the same direction, the dose commitment is much higher for neutrons than for muons. The exposure was 1.6 person-rem from neutrons and only 0.3 person-rem from muons. This neutron exposure is an upper limit since there will be absorption of high energy neutrons in air with an absorption length less than the distance to the site boundary.[25]

The exposure from muons and neutrons was determined by starting with the dose to an individual at the site boundary and calculating dose versus distance from the point on site where the penetrating radiation (Section 3.1) originated to 80 km (50 mi) from the site using the inverse square of the distance and summing over the appropriate numbers of individuals. For muons the dose was received by individuals living only in a portion of the northeast sector. See Table 8. For neutrons the dose was received by everyone.

The exposure from airborne releases was calculated starting with the 0.2 mrem per year dose rate at the site boundary obtained using the Gaussian plume diffusion model[13,15] and determining dose versus distances out to 80 km (50 mi) from the site including ^{11}C decay. The site boundary dose rate was calculated for a given one of the 16

sectors for which population data was available from the 1980 census. The source term used was the concentration and rate of flow from the Neutrino Area Labyrinth Stack. The average wind speed for the months when the releases occurred was used rather than the detailed speeds and directions at a set of given times. The contributions from adjacent sectors were added since the distances to the site boundaries were large enough to result in diffusion across sector boundaries. Most of the exposure occurred within 16 km (10 mi) from the site.

Several of the closed loop cooling systems are reaching levels where potential off-site releases, from these loops, would be detectable but not hazardous. No releases occurred from these closed loop systems in CY-1982. Some releases of radioactive water occurred from sumps collecting water from under areas where protons interacted. About one-third of this volume of water left the site while Casey's Pond (H4 in Fig. 4), the reservoir receiving water from discharges in the three external areas to which protons are delivered, was full. The mean concentration of tritium during the period of release was less than one percent of the Concentration Guide for uncontrolled areas. Also, drinking water in the area is taken from wells rather than from the creek receiving the discharge. Hence, the dose from the release is negligible.

3.5.2 Assessment of Nonradioactive Pollutant Releases

Although it was necessary to chemical treat some waters to control the growth of algae and weeds during CY-1982, efforts were made to keep these treatments as low as possible in order to protect wildlife and fish, i.e., well within guidelines established by the State of Illinois.

There was no significant environmental impact resulting from the operation of the magnet debonding oven (Section 3.4.1). There were no other activities during CY-1982 which created problems with respect to nonradioactive airborne effluents. Heating is accomplished by use of natural gas, liquefied propane gas, or electricity. The bulk of the heating is supplied by natural gas fired boilers located in the Central Utilities Building. The effluents from these boilers are analyzed annually to maintain proper combustion efficiency. A spill of approximately 7570 ℓ (200 gal) of copper fluoborate occurred at the Hazardous Waste Storage Area in CY-1982 (near W45 in Fig. 5). The contaminated soil was dug up and disposed of as hazardous waste. No environmental impact resulted.

3.5.3 Potential Impact of Other Toxic Substances

3.5.3.1 Pesticides

In addition to the water treatments mentioned in Section 3.4.4, the following EPA registered herbicides, insecticides and rodenticides were applied by trained personnel following the manufacturer's instructions:

Roundup was applied to bases of trees in the Village and at Site 38 (W38 in Fig. 4) to control weed growth. Approximately 30 ℓ (8 gal) was applied in CY-1982. A residual level of 1500 ppm was detected in the Village. Roundup is soluble in water and should become diluted to negligible concentrations without environmental impact.

Lithate 2,4D was applied to 0.18 km^2 (45 acres) in 1982 for control of noxious weeds. The areas sprayed were grassy areas, primarily in the Village.

Corn was planted on 9.22 km^2 (2,278 acres) by licensees who applied pesticides and fertilizers. Application of these pesticides (herbicides) was supervised by Fermilab. See Table 9.

TABLE 9

Pesticides Applied by Corn Plot Licensees

Plot Size (km^2)	Plot Size (acres)	Pesticide	Total Applied in CY-1982 (kg or ℓ)	Total Applied in CY-1982 (lbs or gal)
6.25	1545	Atrazine	1401 kg	3090 lbs
9.22	2278	Lasso	5389 ℓ	1424 gal
2.97	733	Aatrex 80W	664 kg	1466 lbs

Sampling was done in CY-1982 for residues of Atrazine, Aatrex 80W, and Lasso mentioned above. No residues were found, hence no evidence was found for any environmental impact.

For mosquito control, an ultra low volume application of CYTHION Premium Grade Malathion was performed at 16 different times. Approximately 7.6 ℓ (2 gal) of CYTHION were used in each application and the following areas were covered: Village and Sauk Circle just south of the Village (Fig. 4), Sites 29, 38, and 43 (W29, W38, and W43 in Fig. 4), the Meson, Proton and Neutrino experimental areas (Fig. 1), and the Industrial Areas (near W43 in Fig. 4).

EATON's AC Formula 50, a rodenticide, was placed in pan-type feeders inside approximately 40 outdoor electrical substations to reduce rodent nesting in this high voltage equipment. Approximately 4.5 kg (10 lbs) was used in CY-1982.

The services of a contract exterminator, licensed by the State of Illinois and using EPA registered pesticides, was retained during 1982 for the control of miscellaneous pests found in kitchens, laboratories and living areas throughout the site.

3.5.3.2 Polychlorinated Biphenyls

An inventory of polychlorinated biphenyls (PCBs) is maintained, and a Status Report as of January 1, 1982 listed 74 PCB transformers and 2,158 large capacitors in use or storage for future use. These PCB items have been labeled as required. These totals differ from last year's totals primarily because many small PCB capacitors were listed as large capacitors. Also, the testing of transformers was completed and some believed to be PCB transformers were lower in PCB concentration than expected.

During CY-1982 a major effort was made to reduce PCB concentrations in transformers and dispose of PCB wastes.[26] Fourteen PCB transformers were processed using the Zero/P.C./Forty system, a Freon® TF hot solvent PCB removal system.[26] Six of these transformers were askarel-filled. Five were then filled with silicone fluid, a substance with better fire protection properties than oil.

A carbon filtering system was tested on two of the silicone-filled transformers. The PCB concentration was reduced from approximately 700 to 70 ppm in the first case when the transformer failed. In the second case the concentration was reduced from approximately 700 to less than 10 ppm. Unfortunately, that transformer soon failed, too. Thus, the problem appears related to the filtering process, but it is believed that the cause has been discovered and can be eliminated.

In addition to removal of PCBs from transformers, 210 PCB capacitors and 37,100 ℓ (9800 gal) of PCB oil in storage was shipped off-site for disposal in an incinerator approved by the U. S. Environmental Protection Agency (EPA). Also, one askarel-filled failed transformer and 38 drums of solid waste contaminated with PCBs were shipped

for off-site disposal. Consequently, the probability of environmental impact from PCB spills has been greatly reduced.

3.5.3.3 Hazardous Wastes

Significant progress was made during 1982 with respect to identification, collection and disposal of hazardous waste in an environmentally acceptable manner. Responsibility for this program was assigned to the Safety Section in CY-1979 and a hazardous waste handling and storage facility was developed at Site 55 (near W55 in Fig. 4). This facility is roofed and fenced, has hardstand and a concrete containment area. An additional facility with concrete containment area for PCBs was developed at Site 3 where the Environmental Monitoring Station is located (Fig. 4). This facility is for inside storage of hazardous materials which are for future use. In CY-1982 a PCB storage building was constructed at Site 55 which is much farther from the site boundary that Site 3. Off-site impact from an airborne release of PCBs will be greatly reduced when PCBs are stored at Site 55.

Over the years it has been the practice to deposit excess materials such as lumber, concrete, building materials and earth on the Meson Area shielding hill. To

assure that none of these materials are hazardous to the environment and none will contribute to the contamination of surface or ground waters, a program to control such deposition was developed during 1979. Rules have been promulgated and responsibility for access and control has been assigned to the Roads and Grounds group. The Safety Section monitors this program. In 1982 burial of wood, paper and other wood products on the hill was halted.

3.5.3.4 Heavy Metals

No copper sulfate was used to treat the ponding systems in CY-1982. There was no evidence of any further impact from the treatment in CY-1981.[7] Copper solution from the etching of printed circuit boards was disposed of as hazardous waste. Chromate treatment of the cooling towers has been replaced by biodegradable treatments. See Section 3.4.5. Only trace amounts of copper were released in the CUB Tile Field. A copper fluoborate spill was cleaned up and disposed of off-site. Thus, the environmental impact from heavy metals released in CY-1982 should be negligible.

3.5.3.5 Chlorides

The potential environmental impact of release of chlorides into the CUB clay tile field (Section 3.4.5) has been evaluated. Assuming the salt released in one year all ends up in the nearest drinking water well (W1 in Fig. 4) and is diluted in the water normally pumped from that well for one year, the concentration would be less than 25% of the applicable limit of 250 mg/ℓ.[27] Thus, the environmental impact should be minimal.

A similar analysis was conducted for the impact from salt applied to Fermilab roads in the winter. A similar result was obtained.

4. Quality Assurance in CY-1982

Water samples were analyzed by Eberline, Midwest Facility, 245 Roosevelt Road, West Chicago, Illinois 60185, for radioactivity from January 1, 1982 through September 30, 1982. From October 1, 1982 through December 31, 1982 Hazelton Environmental Sciences, 1500 Frontage Road, Northbrook, Illinois 60062, performed the analyses. In addition, such samples were counted at the Fermilab Nuclear Counting Laboratory. Tritium and ^{45}Ca analyses were done only by Eberline and Hazelton since Fermilab does not have the necessary liquid scintillation counting system. Each monthly shipment to Eberline and to Hazelton included at least one sample prepared at Fermilab containing known amounts of several of the accelerator-produced radionuclides. Tritium was included every month.

4.1 Analytical Procedures at Eberline and Hazelton

The procedures used by Eberline Instrument Corporation were described in last year's environmental monitoring report.[7] Most of the chemical procedures were taken either directly or with minor modifications from procedures manuals prepared by government agencies.[28,29] Hazelton's procedures are essentially the same.

The samples were subjected to the appropriate one of the following analyses:

Type 1a: Test for ^{3}H (tritium), ^{7}Be, ^{22}Na, ^{45}Ca, ^{54}Mn, and ^{60}Co at surface water sensitivities. See Section 5.

Type 2a: Test for all of the above at ground water sensitivity plus total radium (the sum of ^{223}Ra, ^{224}Ra, and ^{226}Ra) and total thorium (the sum of ^{228}Th and ^{232}Th).

Type 3a: Chemical separation of ^{45}Ca before its determination; otherwise the same as Type 1a.

Type 4a: ^{3}H only, at surface water sensitivity.

Type 5a: Chemical separation of ^{45}Ca and analysis for ^{45}Ca only, using surface water sensitivity.

Type 6a: The same as Type 1a except at ground water sensitivity.

Type 7a: The same as Type 4a except at ground water sensitivity following distillation.

Type 8a: Test for gross alpha, gross beta, ^{3}H, ^{131}I, and ^{134}Cs at ground water sensitivity. This analysis is performed on Fermilab's one community water system and on other drinking water systems on site which supply water to more than 25 people during the work day.

Type 9a: Test for Sr-90 only, at ground water sensitivity.

Separate analyses of two aliquots from the same sample bottle is indicated by changing the letter "a" to the letter "b" on the Type designation.

The specifications for the above analyses are given in Table 10.

4.2 Quality Assurance Samples

During CY-1982 the providing of quality assurance samples by the DOE Environmental Measurements Laboratory (EML) was not funded.[30] Thus, no results are available from that program. As Fermilab has done in the past, we continued to send quality assurance samples to our vendors.

Results are shown in Tables 11 and 12. In general, the agreement with the known concentrations was within the precision specified by Fermilab about half the time. See Table 10. Better results have been achieved on EML samples.[7]

Quality assurance samples were sent for PCB analyses to Gabriel Laboratories, Ltd., 1814 North Marshfield, Chicago, Illinois 60622. The PCB concentration provided by the United States Environmental Protection Agency were 18, 54 and 498 parts per million (ppm). Gabriel Laboratories reported 19.5, 57, and 519 ppm, respectively.

TABLE 10

Specifications For The Analyses Of
Accelerator-Produced Radionuclides in Water

Radio-nuclide	CONCENTRATION GUIDE FOR POPULATION Individual (μCi/mℓ)	Suitable Sample (μCi/mℓ)	Community Water System	SPECIFIED SENSITIVITY AND PRECISION* Surface Water (μCi/mℓ)	Ground Water (μCi/mℓ)
^{3}H	3×10^{-3}	1×10^{-3}	2×10^{-5}	3×10^{-6}	1×10^{-6}
^{7}Be	2×10^{-3}	6.7×10^{-4}	1.3×10^{-5}	5×10^{-7}	5×10^{-7}
^{22}Na	3×10^{-5}	1×10^{-5}	2×10^{-7}	3×10^{-7}	2×10^{-8}
^{45}Ca	9×10^{-6}	3×10^{-6}	6×10^{-8}	3×10^{-7}	6×10^{-9}
^{54}Mn	1×10^{-4}	3.3×10^{-5}	6.7×10^{-7}	1×10^{-7}	7×10^{-8}
^{60}Co	3×10^{-5}	1×10^{-5}	2×10^{-7}	1×10^{-7}	2×10^{-8}

* The precision and sensitivity are stated for the 68% confidence level (one standard deviation). The precision required is the value specified or ± 10 percent, whichever is the lesser precision. The sensitivity is taken to be the minimum concentration which can be detected within the 68 percent confidence level.

TABLE 11

Quality Assurance Results for Eberline

Sample Date	Radio-nuclide	Percentage of Concentration Guide for Surface Waters* (%)	Prepared Concentration (μCi/mℓ)	Ratio of Eberline Result to Prepared Concentration
1/82	^{3}H	0.033	5.7×10^{-6}	1.18
	^{22}Na	7.3	2.2×10^{-6}	1.07
	^{54}Mn	1.0	1.0×10^{-6}	1.05
2/82	^{3}H	3.8	113×10^{-6}	0.92
	^{7}Be	4.6	91×10^{-6}	1.37
	^{45}Ca	104	9.4×10^{-6}	1.05
	^{54}Mn	3.1	3.1×10^{-6}	1.23
	^{60}Co	7.7	2.3×10^{-6}	1.03
3/82	^{3}H	1.9	58×10^{-6}	1.33
	^{7}Be	4.6	91×10^{-6}	1.37
	^{45}Ca	50	4.5×10^{-6}	0.88
4/82	^{3}H	0.15	3.5×10^{-6}	1.05
	^{7}Be	0.23	4.6×10^{-6}	1.12
	^{22}Na	32	9.7×10^{-6}	1.13
	^{60}Co	12	40×10^{-6}	1.01
5/82	^{7}Be	0.15	2.9×10^{-6}	1.08
	^{22}Na	3.3	0.99×10^{-6}	1.15
6/82	^{3}H	20	586×10^{-6}	1.09
	^{45}Ca	26	2.3×10^{-6}	0.96
	^{60}Co	7.7	2.3×10^{-6}	1.22
7/82	^{3}H	0.19	5.7×10^{-6}	1.51
	^{22}Na	6.0	1.8×10^{-6}	1.17
	^{54}Mn	0.99	0.99×10^{-6}	0.81

*Individual in Table 10

TABLE 12

Quality Assurance Reports for Hazelton

Sample Date	Radio-nuclide	Percentage of Concentration Guide for Surface Waters* (%)	Prepared Concentration (μCi/mℓ)	Ratio of Hazelton Result to Prepared Concentration
08/82	^{3}H	3.7	110×10^{-6}	1.14
	^{7}Be	0.43	8.6×10^{-6}	1.23
	^{45}Ca	100	9.0×10^{-6}	0.72
	^{54}Mn	7.3	7.3×10^{-6}	1.09
09/82	^{3}H	2.0	59×10^{-6}	1.13
	^{45}Ca	56	5.0×10^{-6}	0.68
	^{60}Co	7.7	2.3×10^{-6}	1.04
10/82	^{3}H	0.11	3.4×10^{-6}	1.19
	^{7}Be	0.10	1.9×10^{-6}	< 0.26
	^{22}Na	32	9.7×10^{-6}	1.03
	^{60}Co	37	11×10^{-6}	0.88
11/82	^{7}Be	0.07	1.4×10^{-6}	1.25
	^{22}Na	3.3	1.0×10^{-6}	1.15
	^{54}Mn	8.8	8.8×10^{-6}	1.09
12/82	^{3}H	20	587×10^{-6}	0.95
	^{45}Ca	36	3.2×10^{-6}	0.77
	^{60}Co	7.7	2.3×10^{-6}	1.01

*Individual in Table 10

5. References

The appropriate Radiation Protection Standard for penetrating radiation applied to individuals in uncontrolled areas was taken from the DOE Order 5480.1A, Chapter XI. The annual dose for whole body exposure is 0.5 rem when applied to a suitable sample of the exposed population.

The Concentration Guides used in the analyses of the surface water samples for radioactivity were taken from the DOE Order 5480.1A, Chapter XI, Table II, Column 2 (Water in Uncontrolled Areas) and reduced by a factor of three where appropriate for a suitable sample of exposed population. The smaller of the values given for soluble and insoluble forms has been used in each case. The specifications are given in Table 10. The Concentration Guides for airborne activity were taken from the same source, Table II, Column 1 (Concentrations in Air in Uncontrolled Areas), and divided by a factor of three for determining the total off-site potential dose to the public. For tritium the Concentration Guide from Table II, Column 1, is 2×10^{-7} μCi/mℓ. For ^{11}C the Concentration Guide, 2×10^{-8} μCi/mℓ, was taken from the calculations by Yamaguchi.[14]

The Concentration Guide used in the analyses of ground water samples for tritium were taken from the U. S. Environmental Protection Agency regulations for community drinking water systems.[31] The maximum contamination level permitted for tritium is 2×10^{-5} μCi/mℓ and corresponds to an annual exposure of 4 mrem if one uses the supply as one's sole drinking water source. Note that this is 50 times more stringent than the DOE regulation for a suitable sample of the general population which corresponds to 170 mrem/year. The Concentration Guide for the other radionuclides in Fermilab's analyses of ground water samples have been determined by dividing the surface water concentrations for a suitable population sample by 50 (Table 9). The specified sensitivity and precision of the analyses have been reduced to well below these Concentration Guides.

The Air and Water Pollution Standards for nonradioactive pollutants were taken from Chapters 2 and 3 of the State of Illinois Pollution Control Board Rules and Regulations. The waters on site were considered to be in the "general use" category. The values for total hexavalent chromium for general water quality is 0.05 mg/ℓ. The Standards for total copper at the discharge point and for general water quality are 1.0 and 0.02 mg/ℓ respectively, and for zinc are both 1.0 mg/ℓ for surface water and for well water. The Air Quality Standards limit the release for

SO_2 and oxides of nitrogen to 816 g (1.8 lbs) and 136 g (0.3 lbs) respectively, per 252 million calories (per million btu's) of actual heat input in any one hour.

The appropriate regulations for PCBs and hazardous wastes are found in the U. S. Code of Federal Regulations 40 CFR 761 and 40 CFR 260-265, respectively.

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